Student questions: Rene Ong colloquium on "Very High-energy Astrophysics and the Cherenkov Telescope Array"

9/6/17

Question 1: On the slide titled "VHE Gamma Ray Sky c2017," why were so many colored points on the galactic plane and only a scatter of the red ones elsewhere on the plot?
The sources on the Galactic plane are within our Galaxy and those off the plane are largely extragalactic. The different colors correspond to different types of sources, as indicated by the legend. It just so happens that the extragalactic VHE sky is dominated by one source type – active galactic nuclei. However, the Galactic sources come in many different types, hence many more colors.

Question 2: You used the work "pi-zero" a few times (I think that's how you'd spell it), what is it?
Check Wikipedia. A pi-zero is a neutral pi-meson. It is one of the very few hadronic particles (i.e. particles composed of quarks) that decays into electromagnetic particles. The decay is pi-zero → 2 gamma rays. The point is that gamma rays (electromagnetic particles) can be created even in hadronic processes through pi-zero decay. So the acceleration of protons can lead to gamma rays if those protons collide matter to produce pi-zeros.

Question 1: You say that some sources of VHE are very close to a black hole. Is it not coming from the black hole itself?
No it is not. Light, including gamma rays, cannot escape from a black hole, by definition. Technically, they cannot get out from the region inside the event horizon. However, matter falling into a black hole is accelerated and produces radiation. The process of matter falling into a compact object (neutron star, black hole) is called accretion. It turns out that accretion is one of the most efficient processes known to produce outward going radiation.

Question 2: Is there any idea as to the source of TeV emissions from the galactic center? A supermassive black hole or even a collection of black holes that concentrate the source?
Good question. We really have no idea what the source (and mechanism) is for producing the VHE gamma rays from the point source at the center of our Galaxy. In fact, there could be more than one source and more than one mechanism. As mentioned in the previous question, we would like to use a model of accretion of matter onto the central massive black hole as a possible way to explain the power given to the VHE radiation, but the central black hole does not appear to be accreting in any significant amount. Thus, we have a real mystery. The VHE radiation clearly comes from very close to the black hole, but it is not accompanied by strong radiation at other wavelengths! Keep tuned as we learn more about, and hopefully solve, this mystery.

Question 1: How would you use the CTA to observe bodies within our own solar system?
We can observe objects in our solar system if they emit some optical light (i.e. reflect light from the Sun) because CTA has a very large collection area for optical photons. We can also detect bodies that transit (pass in front) of other objects because they would block the light from the more distance object. There are studies for CTA to be able to detect objects in the Kuiper Belt that lies about 30-50 AU from the Sun via this transit technique.

Question 2: What do images of these distant and high energy structures look like in visible light?
First, many of the VHE gamma-ray sources are not even clearly detected in visible light. Sometimes they may lie in the plane of the Galaxy where the visible light is blocked. Other times, there is no obvious visible object to match to the VHE gamma-ray source. For those sources that can be match to visible light sources, the VHE gamma-ray sources generally look much different – generally much smaller and more compact. The visible light generally comes from very extended thermal emission and the VHE gamma rays generally come from an inner core region.

Question 1: What makes one telescope sight better than another? Is it more a function of a clearer sky or some logistical factor?
I think you mean "site". For the CTA site selection, we looked for locations that were moderate elevation (to maximize the Cherenkov light yield and get away from low-elevation mixing layers in the atmosphere) of 1000-2500m, that had a high percentage of clear night (> 70%), and that had reasonable infrastructure to build an instrument of CTA's size. The key factors are how much good data the observatory would get per year and how much it would cost to build and operate.

Question 2: Is there a chance you could observe the same Cherenkov shower in both the Northern and Southern telescope arrays?
We could not observe the exact same shower in the two arrays as the typical showers are a few hundreds of meters in diameter, as mentioned in the talk. However, the two arrays could observe the same source at the same time, in some instances (for sources up at night and visible to both arrays at the same time; the arrays are about 55 degrees apart in longitude). Such observations are envisioned as a way to cross-calibrate the two arrays. For example, the large flare of gamma rays coming from a source could possibly be detected by both arrays at the same time.

Question 1: What is the variability in the footprint size of the Cherenkov interaction showers?
Gamma-ray induced showers are very regular because the electromagnetic processes are uniform and the atmosphere is very deep. Thus, a vertical shower from a gamma ray at a fixed energy will have a relatively constant footprint on the group (~10% variation only). However, the footprint will change somewhat if the energy changes (gradually increases as the energy increases) and it will change significantly if the angle changes. Showers will get larger as the zenith angle increases; by 60 degrees zenith they can be 5-10 times larger on the ground (but not so much larger in the area projected in the plane perpendicular to the shower axis).

Question 2: Are there any current hypotheses to explain the patterns of homogeneous VHE energy at the galactic centers?
Please see the answer to the question above on the Galactic Center.

Question 1: Would you explain the process that creates the short wavelength visible light cascades that cosmic rays induce in our atmosphere?
As mentioned in the talk, Cherenkov radiation is an optical equivalent of a sonic boom. The charged particles move faster than the speed of light in the atmosphere. (The charged particles, usually electrons, move at a speed close to the speed of light. Light, in the atmosphere, is slowed down by the index of refraction of the atmosphere). As a particle moves, it outstrips its own radiation field and that leads to the emission of coherent Cherenkov photons.

Question 2: Would these “blue” cascades be visible to the average person if they were looking in the right direction from the right spot at the right time?
Interesting question. The human eye has the ability to detect single photons. So, there would be a very short (few nanoseconds length) electrical signal generated by Cherenkov photons in your eye. However, the rest of the vision perception system of humans works on much slower scales, more like milliseconds. Thus, the brain would not register that anything had been seen.

Question 1: How will CTA make use of VHE gamma rays to observe black holes, considering even electromagnetic radiation cannot escape them?
See answer to above question. EM radiation will not come from the black hole but from the accretion of matter falling into the black hole. In addition, particles can be accelerated from the twisting magnetic field that thread through the black hole as it spins.

Question 2: What are the types of the small-sized telescopes (SST) in CTA?
We have three types of SSTs. One is a single-mirror telescope being prototyped in Krakow, Poland. In addition, there are two two-mirror telescopes being prototyped in Sicily, Italy and near Paris, France. Each of these SSTs has a primary mirror of about 4m in diameter. See the following website: https://www.cta-observatory.org/project/technology/ for more details.

Question 1: What is the first project scheduled and what is expected to be found when the CTA is finished?
Not quite sure I understand the first part of the question. The schedule for construction and deployment of the initial complement of CTA telescopes is roughly 2018-2024.

Question 2: What will happen if the CTA doesn't get enough funding to complete?
If there is not sufficient funding to build the baseline CTA, CTA will operate with a reduced number of telescopes. The whole technique is very scalable. However, it is crucial that we have enough telescopes in both sites to achieve a performance that is substantially better than existing instruments. That seems to be assured given the current committed funding.

Question 1: You explained that building multiple telescopes will enable us to understand direction of light showers more accurately. How do you know how many telescopes is the most appropriate, not too many but enough to precisely determine the direction?
Good question. Better accuracy is obtained from more telescopes _and_ from better telescopes. In the case of the CTA design, an enormous amount of simulation work was done to find a good compromise between the number of telescopes, the quality of each telescope's reconstruction, and the cost.

Question 2: What are the biggest political, financial, or technical difficulties you face when you are involved in all phases of telescope project (plannning, decision making, construction, deployment) through international collaborations?
Another good question. The biggest difficulty is coordinating the different funding streams from the different countries. Each country has its own (unique) way of approving and funding projects and different timescales for doing this as well.

Question 1: It was mentioned that our galaxy is emitting a significant amount of VHE photons despite being inactive...how is it determined whether a galaxy is inactive or not?
Active galaxies are defined as those having a very bright central core (e.g. in optical, radio or X-rays, and often all three). Only a percent or so of galaxies are active. Our Milky Way is not.

Question 2: It was mentioned that some particles (positrons? not sure) are capable of traveling faster than light travels in air. What particles are these and why is this the case?
Please see answer to question above. Any charged particle can travel faster than the speed of light in a medium (such as the atmosphere), if that particle is going fast enough. However, no particle with mass can travel at, or faster than, the speed of light in a vacuum.

Question 1: Why are the TeV jets so much smaller in extent and volume than the radio lobes and what factors limit the size of each?
Good question. Some of the answer is given above. The TeV emssion seems to generally come from central regions where the graviational or electromagnetic potentials are very high, which is not surprising because of the high energy of the particles required to produce the TeV photons. Radio and optical radiation can (and does) come from much more extended regions, where potentials are generally much lower. Gamma rays are simply hard to make and much more energetic than optical or radio photons.

Question 2: What qualities are you looking for when choosing candidate locations for the CTA/ other high energy telescope arrays like it?
See answer above.

Question 1: Do environmental factors, such as dust, thermal environment, and humidity affect the resolution or efficiency of the telescopes?
Yes, they do. That's why we selected sites where the amount of dust and humidity is low. If dust and humidity are high, the telescopes would typically not be operated. The quality of data would be compromised, and the telescopes themselves would degrade when operated in a harsh environment. For good operations, temperatures need to be between -20 and +30 degrees C.

Question 2: You mentioned that there's an array of 10k+ silicon photomultiplier tubes proposed on one of the telescope designs; are there any concerns about parasitic capacitance/shared noise between the amplifiers of the PMTs which would affect the resolution/efficiency?
Excellent question. This is definitely an issue. The capacitance leads to actual cross-talk (i.e. signals in one pixel migrating to another) that must be understood and controlled. And, as you probably know, the extra capacitance leads to both signal loss and signal degradation (e.g. worse rise-time). This is why the cameras will all be fully assembled and bench tested before being put on a telescope. And, the temperature of the Si-PMs need to be either controlled or well monitored (to do corrections for gain and cross-talk).

Question 1: What are some of the leading theories on what unidentified gamma ray sources could be?
Some fair number of them can existing source types but they lie right in the Galactic plane so that their emission in other wavebands would be obscured. We can slowly identify these by their gamma-ray characteristics, or by making deep and dedicated observations in other wavebands. Other sources are probably something new – perhaps superbubbles, strong stellar winds, OB associations, binary systems of various types, microquasars, and so forth.

Question 2: In what ways can the technology from CTA be used to inspire construction of other instruments/telescopes that operate in different wavelengths?
We do have a very large optical collection area that can do science topics of interest to the optical community. In terms of the technology iteself, other communities could learn from the scaling of the telescope structures (how to build and operate them) and those interested in using Si-PMs could learn a lot from the very large quantity that CTA will be using.

Question 1: Do you expect the CTA to assist in better defining and understanding the some 40% of source types that are currently unidentified?
Please see answer to above question.

Question 2: Do you expect the CTA to lead to important adjustments to the properties of the EBL?
I think that CTA can help to better pin down the EBL and reduce the uncertainties on its density. This is important to really understand if there really is a discrepancy between gamma-ray measurements of the EBL and those from galaxy counts. (The inferred EBL from gamma-ray measurements is close, or below, the expected floor from galaxy counts). Another thing CTA will be able to do is the measure the EBL into numerous lines of sight – to verify that it is uniform, as expected.

Question 1: Why are the largest telescopes (the LSTs) in the CTA close together and in the center of the arrangement of the array?
The LST are sensitive to the lowest energy showers (produced by the lowest energy gamma rays) because they have the biggest mirror collection area. We want these low energy showers to be viewed by more than one LST (ideally 3 or 4 typically) so the LSTs are separated by ~80-100m which is characteristic of the Cherenkov light pool. If we could afford it, we would build all LSTs that would cover all of CTA. However, that would be too expensive. So, the MSTs then take over at higher energies, again spaced by about 80-100m. At higher energies the showers are bright on the ground and so a smaller mirror will work, but the rate of high-energy showers decreases so we need a larger area covered by the MSTs than the LSTs. And so on up to the SSTs, so that CTA can cover a wide energy range at an acceptable cost. It should be somewhat obvious that we don't want the LTS to be at an edge of the array.

Question 2: What is an example of the initial science that can be conducted with the partial arrays during construction of the CTA?
We can do excellent studies of brighter sources (there are many), studies of flaring sources such as AGN and GRBs – especially to tune up observing programs with the full array, and extensive calibration on known sources (spectra, etc.) – a process called scientific verification.

Question 1: These telescopes seem very similar in function to HERA, although it seems HERA is set to measure much less energetic levels and use less technologically advanced telescopes. Is the main difference between the two the levels of accuracy that they measure?
There are similarities. Radio telescope generally have higher precision than the CTA telescopes – i.e. the mirror structures have smaller tolerances for the radio telescopes. This is because the radio telescopes measure the radio wave directly and CTA uses the atmosphere in a Cherenkov light-gathering arppoach. Radio telescopes that track sources also need to have much better precision in tracking than the CTA telescopes because of the much better achievable angular resolution in radio. However, I think that the HERA telescopes do not track so in this sense their mechanics are likely to be simpler than the CTA telescopes.

Question 2: Why is it there are two prototypes for the MST's and why will they differ with hemisphere (As well as differing in the number utilized by hemisphere)? Is it as simple as the Southern site being larger?
There are two prototype MSTs because two different groups would like to build MSTs and there has not (as yet) been a decision to move to only one telescope type. The telescopes are different. The single mirror telescope is more straightforward to build and requires less tolerance on mirror alignment and positioning. It also uses conventional PMTs. The SCT (US proposed two-mirror telescope) is more advanced technologically and more difficult to build and align, but it uses advanced Si-PMs and will have better performance (better shower reconstruction). So, it is a trade-off in complexity and performance.

Question 1: Why are all the high-energy sources concentrated along the galactic plane?
There are many types of Galactic sources that emit VHE gamma rays. There are also ~70 sources off the plane – mostly active galaxies.

Question 2: How can we be certain that these high energy gamma rays are being emitted by dark matter and not normal matter?
The dark matter source would need to be steady (not varying) and it would need to have a unique spectral shape characteristic of the dark matter particle mass and properties. This spectrum would have to be the same from every dark matter source detected. Clearly, one source may not be enough to establish dark matter unambiguously.

Question 1: If having multiple detectors on the ground helps "triangulate" the directions of the rays, is there a point where adding more detectors does not help with the accuracy? In other words, is there such thing as too many detectors?
You will always gain by having more views of the shower. However, for the showers observed by CTA (i.e. produced by gamma rays in CTA's sensitive energy range), the reconstruction performance levels off for showers being viewed by 8-10 telescopes. Thus, viewing a shower with 20 telescopes does not produce much improvement over 10 and is twice more expensive. As mentioned earlier, very extensive simulations were done to optimize the CTA design – basically the best performance possible over wide energy range, all constrained by the total cost or total number of telescopes.

Question 2: If large sized telescopes are more powerful than small sized telescopes and therefore are able to detect weaker and more rays, is there anything that SSTs can do that LSTs can't do? Does bigger always mean better?
The LST are better because they are sensitive to lower energy showers because of their large mirror area. However, because they are bigger, their cameras are far away from their mirror and this limits the physical size of the camera and hence the field of view. The field of view of the LST is only 4.5 degrees and it is 8+ degrees for the MSTs and SSTs. Finally, one LST costs significantly more than one MST and much more than one SST. So, it's all a compromise when one considers light collection area, field of view, and cost.

Question 1: What do you typically look for in galaxies/galactic centers to determine if you should investigate it as a potential source for very high energy?
Generally, we start with objects already known to emit non-thermal radiation – usually in the radio and X-ray (or lower energy gamma-ray) bands. This has led to the discovery of many VHE gamma-ray sources. However, many more new sources were discovered simply by doing blind scans of the sky. For example, HESS has discovered more than 50 Galactic sources from a scan of the Galactic plan, without targeting any particular locations. So, this shows that the field is fertile – both known sources can be readily discovered (if the observatory is sensitive enough) and many new sources, not known in other wavebands, can be discovered.

Question 2: Why was it decided to build more telescopes for the southern hemisphere site of the Cherenkov Telescope Array than the northern site?
Good question. The central regions of the Galactic plane, including the Galactic Center, are much more easily visible in the southern hemisphere. Thus, in some sense, more science can be done in the south. It is also the case that there are more suitable locations in the south that could host an array of the size of CTA-South.

Question 1: When you showed the galactic plane with all the sources that had been found on it, is there a reason that a very large amount of them were found exactly on the horizon?
Please see answer(s) given earlier on this.

Question 2: When selecting the locations for the telescopes was there any particular thing you were looking for other than easy access to the locations?
Please see answer given earlier on this.

Question 1: What were the reasons why a US site was not chosen for the CTA?
The biggest reason came from the fact that the US could not commit to providing some guaranteed funding for CTA. Spain was able to promise a significant amount of funding for the CTA-North site.

Question 2: Why will there be more telescopes in the array in the southern hemisphere than the northern hemisphere?
See answer given just above.

Question 1: Why would variable luminosity changes mean that the source is close to a black whole and why are they so variable?

Good question. The fast variability generally implies that the region over which the particles (that produce the gamma rays) are being accelerated is small. This comes simply from causality arguments. If the acceleration takes place over a very large volume, you cannot vary the output of the emission very rapidly. However, it is true that the small acceleration region may not be near the black hole, but, for example, it could be in knot of plasma moving along one of the jets in the system, perhaps even far from the black hole. So, for some sources, the emission may not be coming from near the black hole. However, through a variety of arguments, including observation of some nearby objects (like M 87), we know that in some sources, at least, the acceleration of particles occurs in the very inner regions. Then since the size is small, it it logically coming from the black hole region. And, accompanying all of observations is a great deal of theoretical research – i.e. detailed models to explain the particle acceleration and emission processes. However, it is absolutely true that we do not yet understand the general way in which active galaxies are powered and how the strong central emission is generated. That is one of the deep mysteries that CTA hopes to help solve.

Question 2: Is the size of the pool the same for every photon or does it depend on speed etc?

It is remarkably invariant with energy as long as the gamma-ray photon has enough energy to initiate a full shower in the atmosphere. That minimum energy is around 10 GeV. The reason why it is rather invariant is because the actual electromagnetic shower in the atmosphere is very compact and almost point-like in its Cherenkov emission for gamma-ray energies in the GeV and TeV energy range. As the gamma-ray energy gets larger, however, the showers do increase in size. Thus the SSTs can be spaced somewhat further apart (and cover more area on the ground) than the LSTs, for example.

Question 1: That was a great lecture on CTA. Your delivery was especially confident. Where did you learn to do public speaking so well?

Thank you. Practice makes perfect. Teaching also helps. Good feedback from a good audience (as we had the other day) is also really helpful. Finally, it helps to really enjoy what you do.

Question 2: So, is there a CTA study going on at Whipple Observatory, or is the only CTA going to be finished by 2024? Thanks.

The intial complement of CTA telescopes should be largely constructed by 2024. However, the full CTA baseline arrays will most likely not be completed by then. Thus, we expect that additional telescopes (e.g. of the type being prototyped at the Whipple Observatory) could be added as funding is secured. A great thing about CTA is that is expandable.

Question 1: What are some of the goals that CTA has in the near future in regards to the exploration of gamma rays? In other words, how does CTA continue to improve its ideas in regards to understanding the origin of cosmic particles?
This is really a very general question. I tried to provide a number of specific answers to this question in my talk – please see the posted slides.

Question 2: A nice comparison of La Palma, Spain, and Paranal, Chile CTA locations is that these two areas are deserts. What areas on the Earth are best for collecting data, and what are some challenges CTA's have on these sites? Thank you
Please see answer given above to previous question(s) on what factors went into the CTA site selection.

Question 1: Why are the majority of the telescopes for CTA going to be in the south? 99 vs 19 seems like a lot.
Yes, it is a big difference in the number, but remember that 70 of the telescopes in the south are SSTs. So, for the MSTs and LSTs, one would compare 29 telescopes (S) to 19 telescopes (N). The reason why the south has more was answered in previous question(s).

Question 2: The VHE gamma rays clearly are affected by the ISM. What kind of things can we infer about the source from looking at a particular location and seeing, say, radio emission (I believe you said this was one of the effects of the ISM on the gamma radiation).
Actually, I think that I said that gamma rays are affected by intergalactic radiation fields. So, gamma rays from very distant extragalactic sources can be affected by IR photons of the extrgalactic background light. The ISM is generally considered to be the material between star systems in our Galaxy – hence gas (atomic and molecular) and dust. Gamma rays generally go right through the ISM in our Galaxy, unlike other wavebands. That's why we can see the entire Galaxy with gamma rays.

Question 1: Can your research with VHEs and the new CTA provide any insights into dark energy?
This was asked in the lecture. The answer is that CTA is not really designed to probe dark energy and that there are other, more appropriate, telescopes that are being built for this work – e.g. LSST, DESI, Euclid, WFirst, and so on. CTA can make a big impact on dark matter research.

Question 2: What is the frequency of events that can be detected by the new CTA (hourly daily, weekly, yearly)?
The dominant rate of triggers for CTA comes from (proton) cosmic rays. At the larger CTA-South array, the cosmic ray trigger rate will be around 5 kHz. In other words, there will be 5,000 very energetic cosmic ray particles detected by CTA every second. Rather remarkable actually. The rate of gamma rays will depend on the source strength. For a strong source like the Crab, that rate will be on other of 5 Hz – also rather incredible that 5 VHE gamma rays per second reach CTA every second from the Crab.

Question 1: I am aware that observatory locations have been chosen in areas with minimal light pollution from local cities. Are HEV readings potentially disturbed by light pollution experienced in cities? If so, what precautions do you take to assure your site is not impeded on over time?
I am not sure what you mean by HEV readings, so I cannot answer that part entirely. The light pollution affects the energy threshold of CTA (i.e. more light will somewhat raise the low-energy threshold), but once above threshold the night sky background does not appreciably affect the gamma-ray point accuracy and energy resolution. Also not sure what "impeded" means in this context. Of course we would not build on a site where there would be any real possibility of not being able to go to the site. Any sites on military installations, highly protected land, etc. were not considered.

Question 2: What time frame do you expect to be able to detect your source diameter once the sites are operational? You mentioned in the slides, you hope to be able to capture the entire galaxy TeV. Is this diameter dependent on your instrument size, location?
This question needs to be posed a bit better. The field of view of the MST and SST portions of CTA is around 8 degrees (square, so 8 deg x 8 deg). Thus, CTA could observe, say, an 8 deg portion of the Galactic plane or 64 square-degs around the Galactic Center, at any given time. The entire Galactic plane (360 degs by roughly 6 degs) will be surveyed by many overlapping pointings of CTA.

Question 1: What is the source of variability in the data on the luminosity plot?
We honestly do not know yet. There are a variety of possible explanations. Generally the variability is thought to be associated with small knots of plasma that are ejected into an acceleration region. Through the study of variability from AGN sources like PKS 2155 (shown in the talk), we have learned something quite remarkable – that the variability has a certain stochastic pattern and it is generally consisent with red noise (look that up) and thus is likely to be cause by successive random injections of plasma in a completely incoherent way. But the real details of the underlying mechanisms are, as yet, still unknown, and thus very fertile science for CTA to tackle. For questions like this, correlated (especially simultaneous) observations by CTA with other waveband instruments will be very important.

Question 2: Can you provide a link to information that explains the process shown on your slide "imaging atmosphere Cherenkov technique"? In other words, how is the incoming particle converted to blue UV light?
The basic principle of Cherenkov radiation was described in answer to earlier question(s). You can look up "Cherenkov radiation" in Wikipedia. The Cherenkov radiation comes about because the high-energy gamma ray produces a shower of electrons/positrons that move relativistically down through the atmosphere. The size of the Cherenkov light pool comes from the location of the electron/positron shower in the atmosphere (around 10km up) and from the index of refraction of the air at that height – giving an opening angle of 1.3 degrees and a footprint on the ground of about 250m diameter. This thus explains the "atmospheric Cherenkov technique" in the above quotes. "Imaging" comes from the fact that the telescope cameras each have many pixels that record an image of the Cherenkov light in the atmosphere.

Question 1: What is your best guess for the identification of the unknown sources of VHE which seemingly surround the center of the galaxy?
Best guess, but probably not right (or not fully right for sure);
The central source (Sgr A*) comes from accretion onto the black hole that is not evident at other wavebands or from a source very close to the black hole that is not easily detected in other wavebands. The sources nearby Sgr A* are a combination of actual point sources (supernova remnants, pulsar wind nebulae and perhaps binary sources) and relatively complicated diffuse emission caused by the high cosmic ray densities and the ambient material. If dark matter is predominantly in the form of one WIMP with a unique mass, it is likely that there will be a halo of gamma rays around the Galactic Center.

Question 2: Could you explain further why there is little to no activity at the center of the galaxy which has been identified as a super massive black hole?
There is very little activity at the Galactic Center in essentially all wavebands. This is generally thought to be because the center is "starved" – i.e. there is very little mass in which to accrete onto the black hole. Also, the sources outside of Sgr A* that are detected in most wavebands are quite weak. The situation is completely different in GeV and TeV gamma rays where a very strong source is clearly observered right from (or very close to) the central massive black hole.

Question 1: Why was the Spain location was selected over the AZ location for the CTA?
Please see answer above.

Question 2: Does the energy level of the super-high energy protons discussed decrease over time?
This question needs to be phrased better – how can the energy level change for particles at some energy? I will assume that the question was asking about the flux of the particles. The extremely high energy cosmic rays have energies above 10^20 eV (i.e. Joules of energy in a single particle). The flux of these seems constant over the last 20-30 years of observation. So, from direct measurements, it does not appear that their flux is changing with time on a yearly timescale. There are indirect measurements that imply longer-time stability for these particles. We also don't know if they are all protons – in fact it is likely that they are a combination of nuclei species. If interested look on the web for "ultrahigh energy cosmic rays".

Question 1: The Supernova that you showed where it looks like it splits into two seperate masses, what causes this object to split perfectly like it was imaged in your slides?
Supernovae explode and produce remnants with many different geometries. Not all are so symmetric. However, they tend to be more symmetric when young, as SN 1006 is – it is only 1000 years old.

Question 2: I noticed that you had the age of the supernovas in your slides, I am unfamiliar with the process of how to age these, how do you go about doing this?
For some supernovae (very few) there are known dates for the explosion that were seen on Earth. For almost all, however, the explosion was not seen on Earth. Then, we have three things that are related: age, size and expansion rate. If you know two, you can get the third. Clearly to get the size, you need a distance to the object. So, the supernova remnant age determinations involve a host of various measurements.

Question 1: What are the leading theories regarding what the dark UNID spectra represent?
This was discussed in earlier answers. There are many possible object that could make up the UNID sources.

Question 2: Why are there TeV gamma ray hot spots on only some portions of the shock wave of certain supernovae?
Good question. As far as we know, it is at these locations where the shock is highly compressed. The compression leads to amplification in the magnetic field in these regions. That, in turn, leads to particle acceleration to higher energies. In the supernova remnant example I showed (SN 1006), the X-ray data clearly shows high compression (and relatively thin regions) that leads to synchrotron radiation (relativistic electrons radiating in the magnetic field) in the X-rays. The TeV photons are thought to arise from the inverse-Compton process where photons from the synchroton radiation are scattered off the relativistic electrons to higher energies.

Question 1: How much does each telescope cost (small, medium, & large) and what is the total budget for the Spain site?
Approximate costs: 1 LST = $8M, 1 MST = $2.5M, 1 SST = $0.8M. The total budget for the Spain site, including telescopes, infrastructure and computing (but not people) is about $85M.

Question 2: Where would be the best place to search for dark matter in our galaxy and/or universe using the CTA observatory?
In the nearby halo of the Galactic Center. This will be the prime target for CTA in the dark matter search.

Question 1: If the detection of high intensity TeV gamma rays at the Galactic Center of the Milky Way are primarily due to an astrophysical source and not dark matter, Can you either speculate or provide what the current theories are for what this source might be?
Please see various answers above. It’s quite complicated and we really don’t understand the region at all yet.

Question 2: Based on the current angular resolution capabilities, how close to the SMBH's Schwarzschild radius are we detecting these high energy emissions?
The angular resolution of CTA is not good enough to directly image anywhere close to the SMBH Schwarzschild radius. However, we can infer a maximum size of the accleration region by causality arguments, as discussed previously. With the shortest variations seen, VHE gamma-ray observations are approaching 10-20 times the Schwarzschild radius. Presumably CTA will see even shorter variations from some sources and push this down even further.

Question 1: Have there been any research attempts to correlate the massive unknown energy emission sources detected at the center of our galaxy with the presence of Dark Energy or Dark Matter?
Not dark energy because its effect would not be significant enough in the local universe. Absolutely regarding dark matter. There have literally been hundreds of papers speculating that some components of the GeV or TeV emission are caused by dark matter. For most people, there is (as yet) no convincing evidence of a dark matter signal.

Question 2: Has there been any discussion within the Very High Energy Astrophysics community, on the possibility of the unknown energy source being an emission from the black hole that is reported to be at our galaxy center?
Yes, lots and lots of discussion. Please see answers to earlier question(s).